Hydrogen injection into the gas grid: Current status and future potential

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Hydrogen injection into the gas grid (HIGG) is an interesting application of power-to-gas that offers new opportunities for flexibility and decarbonisation in energy systems. The gas grid can provide a useful outlet and transportation mechanism for hydrogen, and the gas grid's inherent storage capacity ("linepack") could be exploited, absorbing fluctuations from the electricity grid, via power-to-gas. Many countries have extensive natural gas grids; HIGG is an option that would enable these valuable assets to continue operating whilst reducing carbon impacts.

This work explores the technical and economic status of, and outlook for, HIGG, including the physical effects of hydrogen on the infrastructure, and the challenge of how to value hydrogen in the gas grid. The current status of HIGG is considered through a review of real-life projects and modelling studies.

Although challenges exist, it is found that HIGG is technically feasible. Demonstrator projects in a number of different countries show the considerable interest that exists for HIGG. However, in present-day conditions, real-life projects and modelling studies struggle to find viable business cases. Although it would be a vast and costly undertaking, there is interest in complete conversion of gas grids to hydrogen, to enable decarbonisation.

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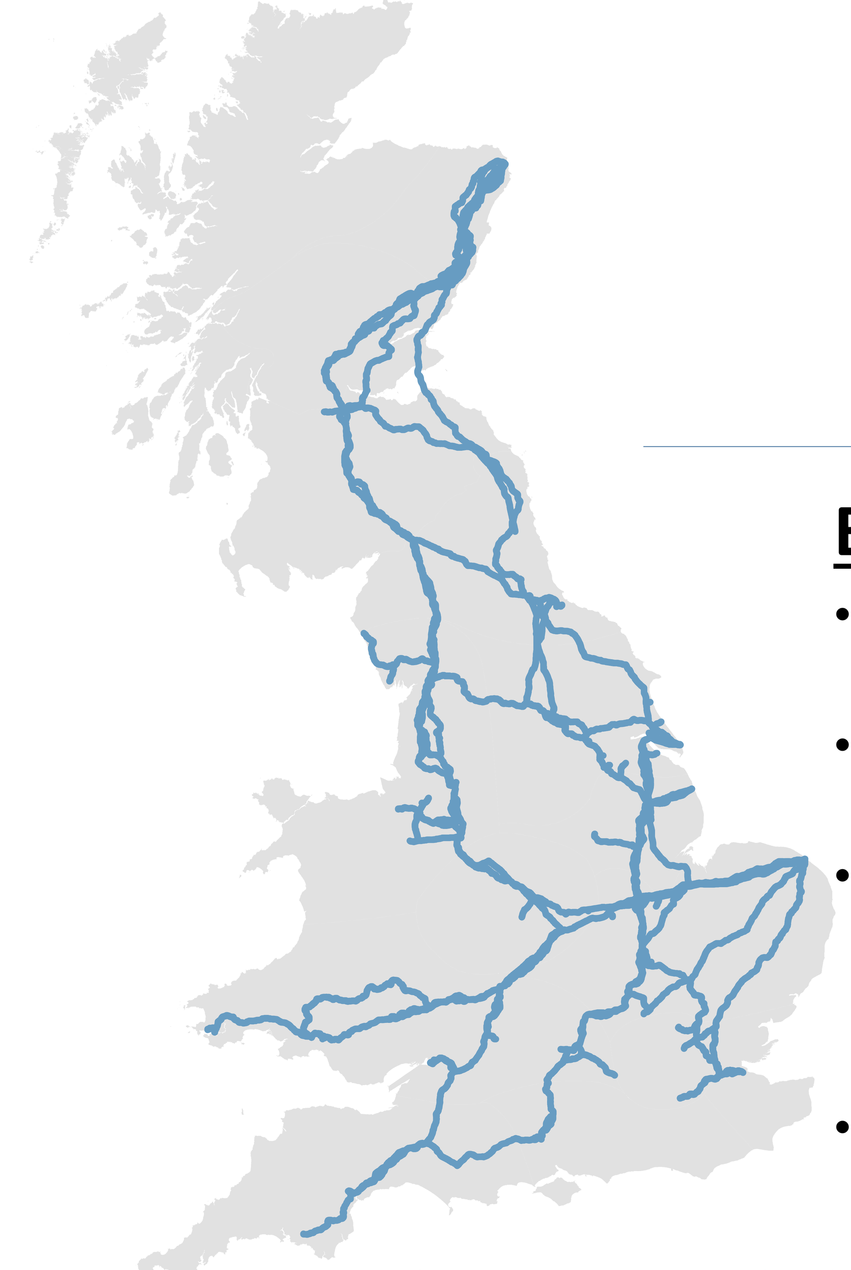
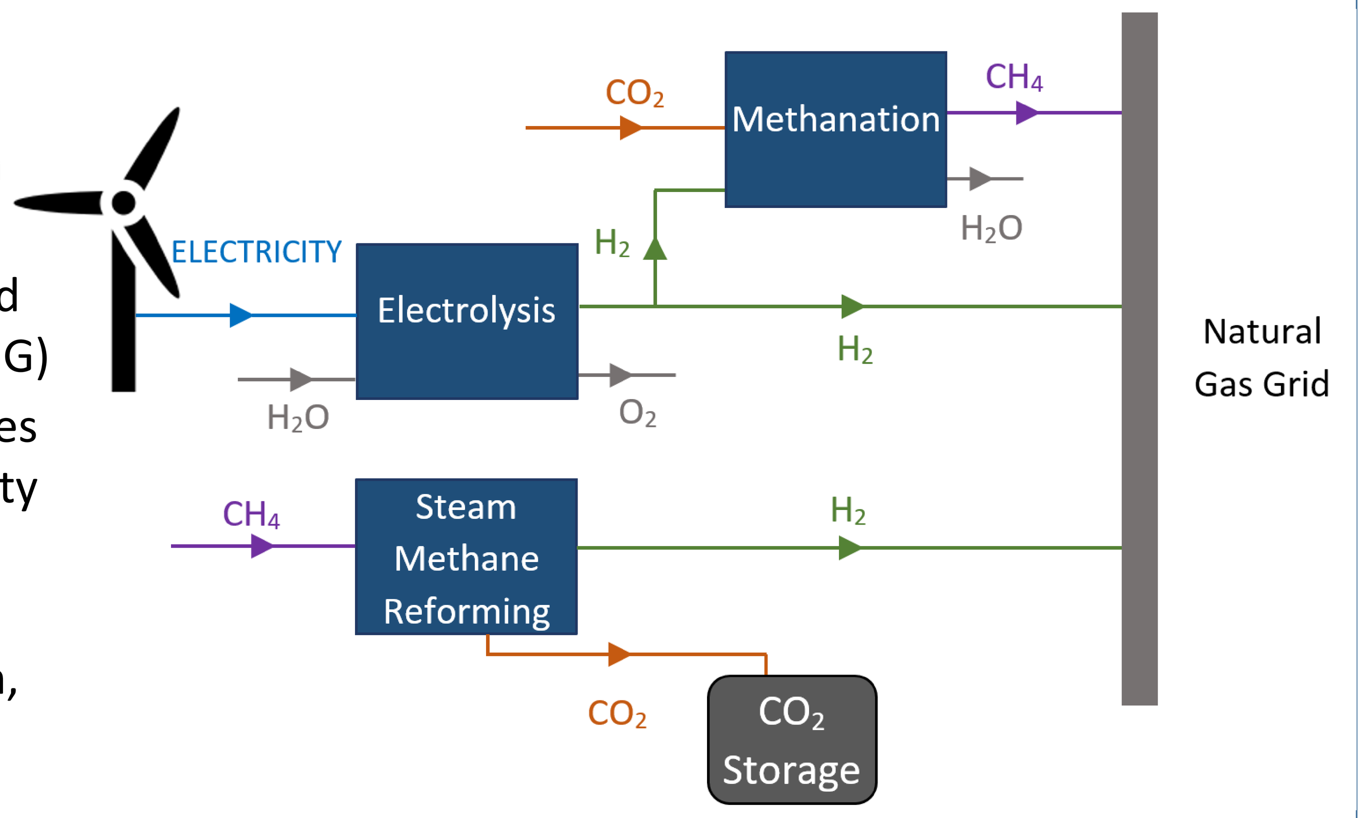


Map of the UK National Transmission System (NTS) [1]

Background

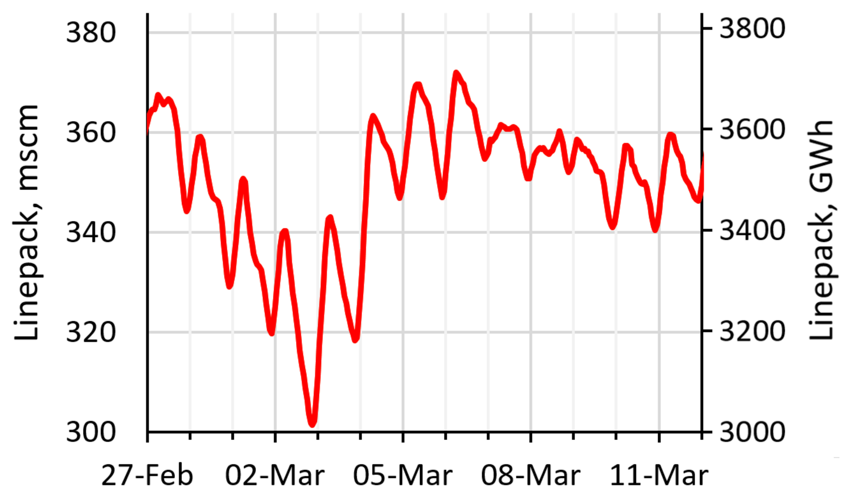
- Power-to-gas (P2G) provides an opportunity for increasing flexibility in energy systems while also reducing greenhouse gas (GHG) emissions.
- An application of P2G is to directly inject the hydrogen into the gas grid (HIGG), or to synthesise methane and inject this into the gas grid (MIGG)
- For countries with extensive gas grids (e.g. the UK, where 86% of homes are served by the gas grid), P2G for the gas grid presents an opportunity to reduce GHG emissions, meanwhile exploiting its benefits for transportation and storage of energy.
- However, there are practical issues to overcome with gas grid injection, especially for HIGG. Meanwhile the economic outlook for injection is challenging in the current policy environment.



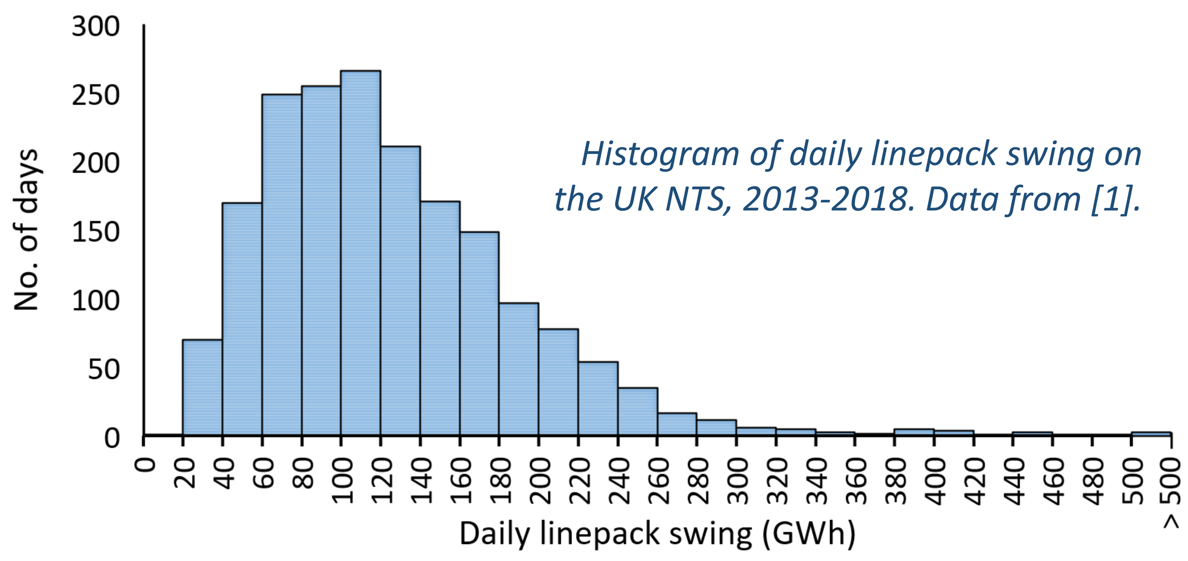
Pathways for hydrogen injection into the gas grid [2]

Why inject?

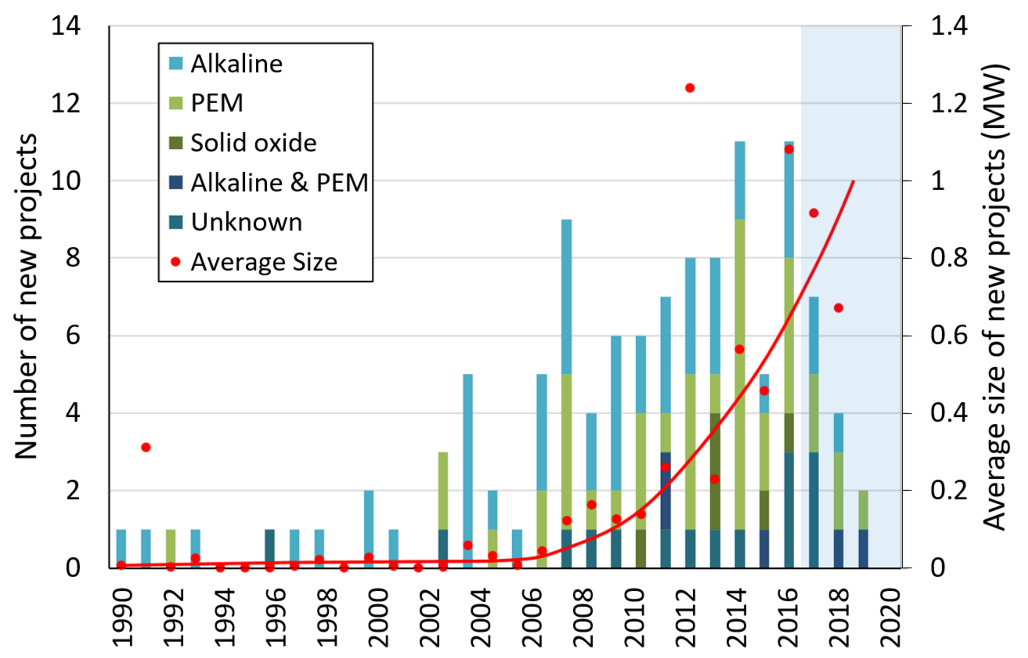
- Gas grids are extensive (> 5,000,000 km of natural gas pipelines worldwide), and are a valuable infrastructure for the transmission, distribution and storage of energy, however their role in a low- or zero-carbon world is uncertain.
- Partial HIGG can reduce the GHG content of gas grids, whilst also acting as a stepping stone to complete conversion of grids to hydrogen (e.g. as considered in the H21 NoE project [3]).
- HIGG also provides an outlet for hydrogen from P2G.
- Gas grids have inherent storage capacity, known as linepack, based on varying pipeline pressures. Figures below show UK NTS linepack over two weeks in 2018 and a histogram of linepack usage.
- This is used for balancing gas supply and demand, but it shows that there is significant capacity for absorbing gas from P2G at times of excess electricity supply.



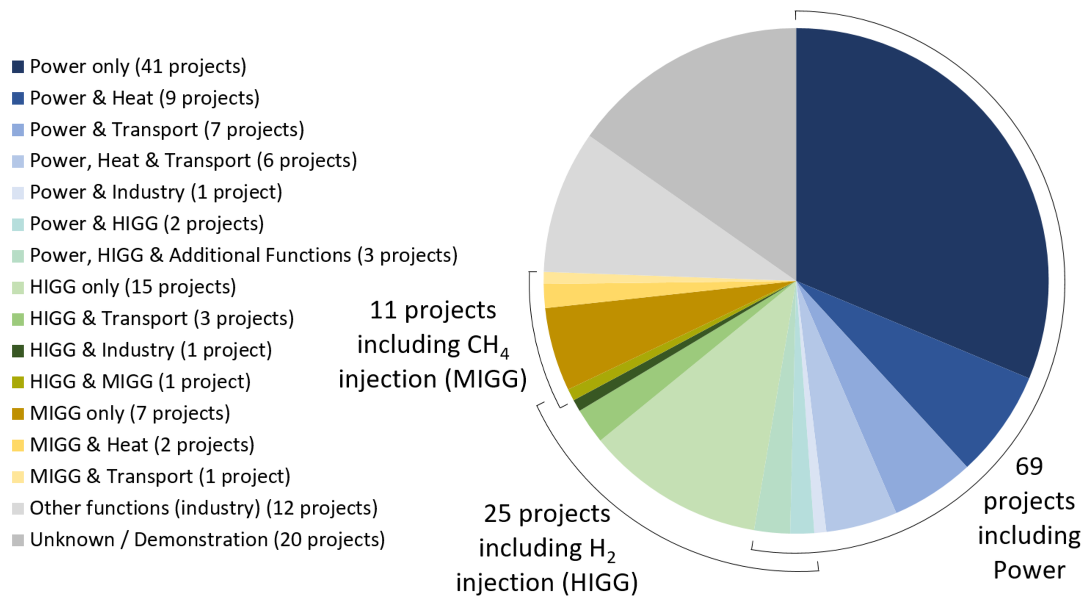
UK NTS linepack in February/March 2018 [1]



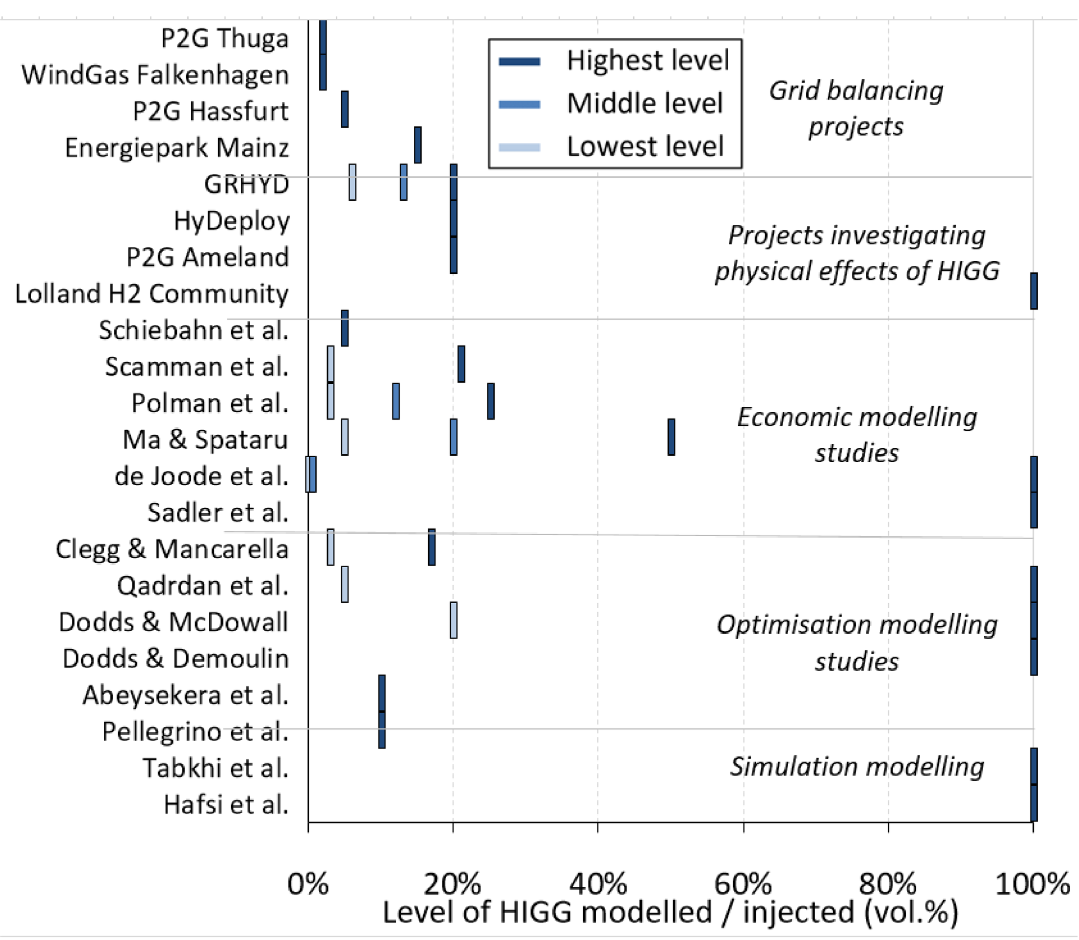
Histogram of daily linepack swing on the UK NTS, 2013-2018. Data from [1].



Timeline of new P2G projects going into operation [2]



Functions of P2G projects (transport-only applications are excluded) [2]



HIGG level represented in real projects and modelling studies. "Lowest", "middle" & "highest" describe where multiple levels are represented (in different scenarios) [2]

Global study of power-to-gas and hydrogen injection

- A global review of P2G projects and modelling studies was performed, focussing on injection into the gas grid.
- Excluding transport-only projects, 131 P2G projects were identified, of which 25 included HIGG and 11 included MIGG.
- Notable projects include Energiepark Mainz (Germany), which has 3.75 MW of electrolysis capacity and injects H_2 into the 6-8 bar gas grid, and newer projects such as HyDeploy (UK) and GRHYD (France).
- Various economic studies of HIGG have been performed, assessing business cases or calculating the levelised cost of H_2.
- Several studies used simulation or optimisation to model the electricity and gas systems and their P2G interactions.
- A variety of modelling methods have been used, but often the representation of P2G, HIGG and linepack is over-simplified.
- More detailed representations can be challenging due to the increased modelling complexity.
- There is mostly good agreement between projects and studies on allowable HIGG levels, although some studies seem overly pessimistic compared to the achievements of some real-life projects (with up to 20 vol.% injection).
- Across all projects and studies it is clear that the economic case for HIGG is challenging. Real-life projects are still at the demonstration stage, yet to find commercial application. Economic studies require policy support or external markets (e.g. grid balancing) to find profitable business cases.

Technical challenges for injection

Whilst it is possible to inject hydrogen into existing natural gas pipelines, there are various practical and technical issues that must be overcome.

Practical issues

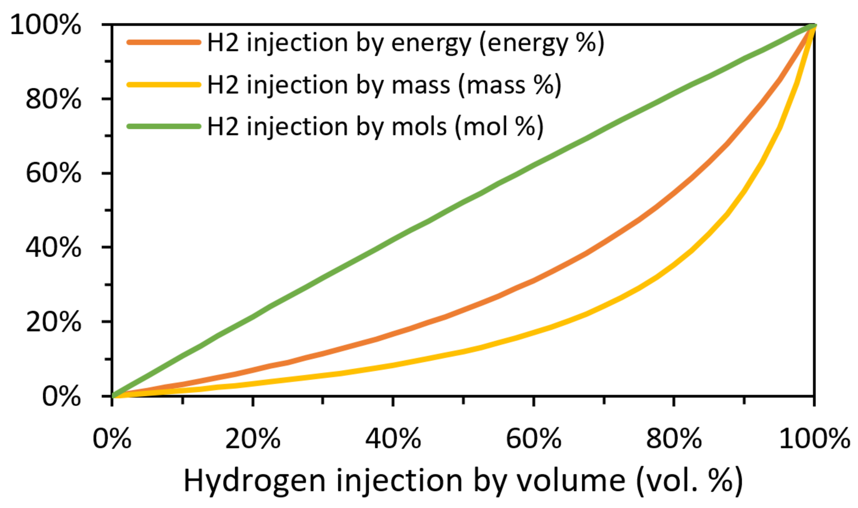
- H_2 can embrittle high-strength steels in high pressure gas pipelines; this process is not well understood. Embrittlement is not a concern in polyethylene piping, which is used increasingly in distribution systems.
- Some gas compressors (centrifugal compressors) are unlikely to be sufficiently powerful to achieve similar levels of compression with H_2.
- All appliances "downstream" of H_2 injection must be able to operate with the hydrogen mix. This is an issue on transmission systems, which feed extensive areas and specialist equipment e.g. CCGTs.
- Hence constructing brand-new H_2 transmission systems may be preferable to HIGG. HIGG in distribution systems is more appealing.

Key properties of hydrogen and methane

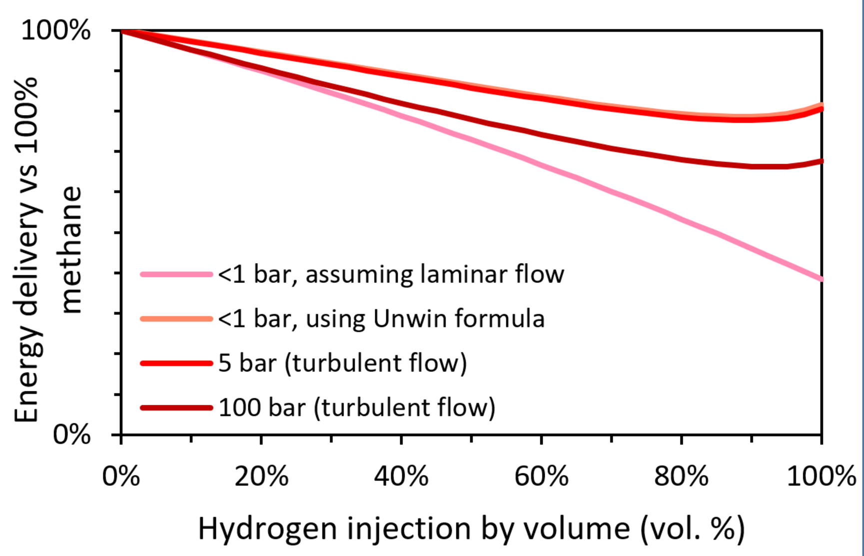
Property (at s.t.p)	H_2	CH_4
LCV (kWh/m³)	3.0	10.0
Density (kg/m³)	0.090	0.716
Dynamic viscosity (10^{-5} Pa s)	0.84	1.03

Flow characteristics

- H_2 differs thermochemically from natural gas, which affects its pipeline behaviour.
- The volumetric energy of H_2 is approximately 1/3 of that of natural gas.
- Factors such as viscosity and compressibility make the behaviour more complex.
- Interaction of these factors depends on flowrate, pipeline geometry, thermal properties and hydrogen injection level.
- Injection of up to 20 vol.% is compatible with existing infrastructures but a higher level may require upgrades.



Relationship between hydrogen injection level measured by volume, energy mass and mols



Energy delivery of a pipeline with HIGG under different conditions compared to pure methane

Outlook for hydrogen injection

- There are technical challenges for hydrogen injection into existing gas grids, but mostly they are well understood, and can be managed.
- Injection into existing low pressure distribution grids is more appealing than high pressure transmission grids due to material and logistic factors. However, new hydrogen transmission pipelines can be purpose-built.
- Partial HIGG has small GHG benefits, but could be a stepping stone to complete conversion. The inherent flexibility of gas grids could also be exploited by P2G and HIGG.
- There is considerable global interest in P2G and HIGG, as shown by the number of demonstration projects and modelling studies.
- However a clear economic case for HIGG is likely to require policy support or access to new (e.g. flexibility) markets. Reductions in electrolyser capital costs will also be beneficial.

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